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Office of Planning and Consumer Programs
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
400 Seventh Street, S.W.
Washington, DC 20590

Re: *Docket 2000-9663*
Dynamic Test Procedures

Dear Sir or Madam:

The following comments are submitted for your consideration relating to the issue of the creation of a dynamic rollover test method for purposes of regulation and consumer information.

As noted in my comments submitted in January, 2000, there can be no dispute that the time has come to address the issue of vehicle rollover. The marketing of sport utility vehicles as on-road, passenger-carrying, station wagon replacements has increased the fatality and severe injury rates dramatically since the early 1980's. The manufacturing community continues to market the vehicles for these uses because the profit margins are breathtakingly high in comparison to other vehicles in the line-up. I commended you at the time for addressing the issue, but urged you to reconsider whether "consumer information" <u>alone</u> was an adequate step towards regulating safe design.

A lot has occurred in the area of rollover since January, 2000, not the least of which was the high profile nature of the Firestone tire/Ford Explorer debacle resulting in the creation of the TREAD act, including your current mandate. I hope you find my comments helpful.

SUMMARY OF COMMENTS

The following is a summary of my comments:

- If the auto industry is going to continue to market SUV's as safe and stable passenger-carrying, station wagon replacements for use on freeways at high speeds, we must have a dynamic rollover test to ensure that the vehicles perform safely in emergencies.

- Although SSF is clearly a primary factor in predicting whether a given vehicle design will remain stable under likely operating conditions, consumer information alone is not the appropriate answer to the rollover problem.

- Rollover accidents are typically preceded by loss of vehicle directional control. Vehicle directional control is an important aspect of vehicle design and is controlled by the designer, not by the consumer. Allowing the industry to blame loss of vehicle control all on the consumer is not appropriate.

- As reflected in the sources cited hereinafter, the evaluation of vehicle design in "emergency" situations is an absolute must when considering safe design. Unless maximum stress is placed on the design, the threshold limit of performance, including a margin of safety, is never achieved.

- The Agency should adopt a dynamic test maneuver or maneuvers that, at a minimum, include [a] a multi-turn maneuver that requires severe steering wheel inputs and rates that exceed the known maximums demonstrated by consumers in driving studies [b] an assessment of the roll angles, roll stiffness characteristics, lateral load transfer characteristics, lateral acceleration capability, yaw rate tendencies, and understeer/oversteer characteristics at high levels of lateral acceleration [c] an assessment of the effect of roll momentum with an effort aimed at determining the natural resonance/frequency of the roll response in multi steer events and [d] a requirement that the vehicle remain stable – no wheel lift – in severe turning maneuvers on flat, level surfaces. The maneuvers currently being evaluated [CU/Fishhook/ etc …] are all examples of the type of maneuvers capable of being used to rank good versus bad performance.

1. THE SETTING

The automotive industry has long contended that rollovers are unpredictable events caused by a combination of the driver, vehicle and the environment. The claim is designed to focus responsibility away from vehicle design and onto a combination of driver error/fault and extraneous roadway factors [lips, grass, dirt, etc ...]. By shifting emphasis away from design, the industry hopes to persuade the Agency that current vehicles are reasonably safe and that drivers are the root of the problem. The industry's claims are wrong, shallow, and misleading.

Although there can be little doubt that drivers and the environment are involved in every single vehicle rollover accident, the auto industry has known for years that the "primary" problem is the design of the vehicle. For instance, as early as 1988, the MVMA retained an outside consultant to conduct a study to determine why light trucks, and especially the SUV segment, had elevated rollover rates. In particular, the MVMA asked the consultant to determine whether the cause for the elevated rates was the driver, the vehicle or the environment. After conducting extensive work on the issue, the consultant replied as follows:

> Coming to the bottom line, it is hard to defend the proposition that the elevated rollover rates of light trucks, particularly the utility vehicles, are basically due to their drivers or to their use in 'high-risk environments'. Certainly, those factors play a role in explaining the light truck rates, but the evidence now suggests that <u>vehicle factors must make a major contribution</u>.[1]

Despite the conclusions of the industry's own research in 1988, the industry continues to harp on the proposition that the rollover problem, which everyone agrees is severe, is a driver problem as opposed to a vehicle problem. Ignoring the industry's own internal work is not going to fix the problem.

2. ROLLOVER TESTING: THE HISTORICAL SETTING

Although we are routinely led to believe to the contrary, rollover testing has been conducted for decades.[2] Early rollover testing was primarily aimed at evaluating the

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[1] Terhune, et al; "*A Study of Light Truck and Passenger Car Rollover and Ejection in Single Vehicle Crashes*" [May, 1988].

[2] See, e.g., SAE 560310: "*Industry Report on Automotive Safety Research*", Fredericks, Ford Motor Company [1956] and SAE 720495: *"Rollover Testing"*, Wilson and Gannon, GM [1972][noting that earliest rollover testing dates back to 1934].

consequences of the event versus the cause of the event. The reason for this is best summarized by engineers working at Ford in 1962 when they stated: "the modern automobile with its low center of gravity is hard to roll under controlled test conditions."[3]

Testing aimed at causing a vehicle to roll began in earnest following creation of the military Jeep.[4] The objective was to determine why drivers of the M-151 might inadvertently bring the vehicle to an operating state in which the potential for rollover was large, given the need for some emergency steering or braking control.[5] The study focused only on the rollover phenomenon which occurs as a result of maneuvers performed on paved, level surfaces as a result of driver control actions, and whether there was a particular maneuvering sequence that imposed a maximal challenge to the rollover immunity of the Jeep. The objective was chosen because motor vehicle engineers tended to believe that a motor vehicle having the size and shape of representative motor cars would never exceed its rollover threshold on smooth, level surfaces, irrespective of the maneuver called for by the driver. As noted in the following passage, the researchers referred to this rollover scenario as "elusive":

> A more elusive overturning scenario than those mentioned above is the case in which a turning vehicle rolls over on a level, smooth surface without encountering [a] an obstacle or [b] a sudden increase in tire-road friction, for example. The term 'elusive' is used because a static analysis of the mechanics involved is unable to indicate whether a given maneuver will cause a rollover event. Rather, it is necessary to calculate the directional response to steering and braking control inputs to determine whether a rollover event will occur.
>
> It should be noted that rollovers will <u>not</u> occur in maneuvers performed on level, smooth, constant-friction surface when a driver steers and brakes in a <u>normal</u> manner, namely, to accomplish typical path and speed-keeping objectives. Only when a driver finds it necessary to perform an <u>emergency maneuver</u>, that is, he steers and brakes so as to approach the maximum forces that can be generated

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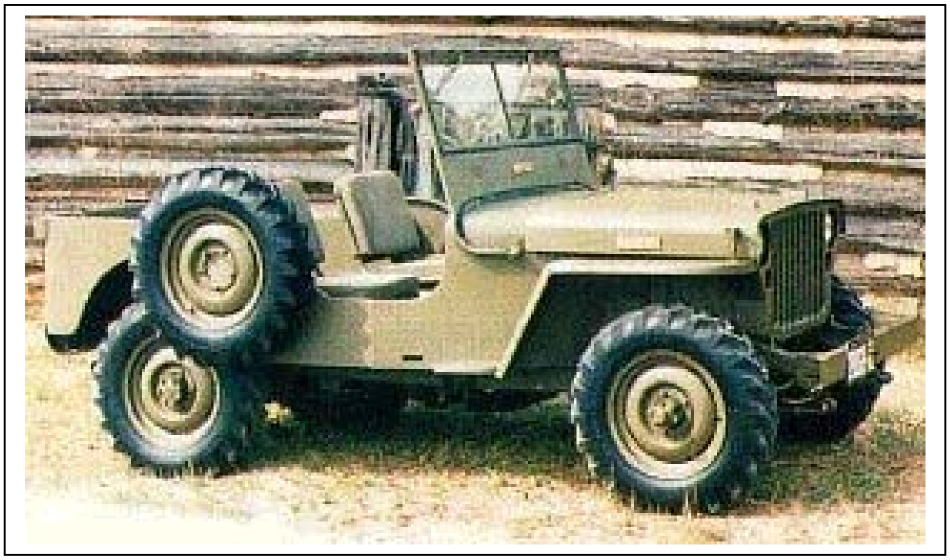
3 See, e.g., SAE 620265: "*Automotive Crash Research*", Fredericks, Ford Motor Company [1962].

4 See, e.g., Babione, R.W.; "*Accidental Deaths in Military Vehicles*", U.S. Armed Forces Journal, VII[16]: 1565-66 and Department of the Army, "*Accident Reports Involving M151 Ford Jeeps*"; Director of Safety, Headquarters, U.S. Army, Europe [1969].

5 See, Sharp and Segal, "*An Investigation of the Rollover Dynamics of a Military*"; UM-HSRI-79-40, July 3, 1979.

by the tires, is it possible or likely that a rollover threshold will be exceeded.



The much publicized roll problems involving the Corvair further heightened industry awareness of the risks associated with vehicle rollover and the need to conduct rollover resistance testing. The Corvair problems also helped focus research on the role of suspension instability in causing or contributing to vehicle instability, and the necessity of evaluating suspension characteristics in the context of overall vehicle performance. Suspension instability is defined in the following passage:

> [B]oth analysis and experiment have shown that an independent suspension with a geometry yielding a high roll center leads to significant 'jacking' forces at high g levels when the side forces on the tires are very asymmetrical, right to left. … a 'jacking' force leads to a reduction in track width and a further increase in roll center height which, in turn, increases the 'jacking' force and thereby reinforces the process, a process which could be described as a 'suspension instability.' A 'suspension instability' … can lead to roll instability, as the CG of the vehicle rises and the track width of the unstable suspension is reduced.
>
> The question thus arises as to why a vehicle developer would use an independent suspension design for which the possibility of 'suspension instability' exists. … In general, accident records

> indicate that vehicles of this type are nearly always over-involved in accidents which involve a rollover incident.

During the same general time frame, the industry was forecasting strong growth in the four wheel drive market. Internal surveys indicated consumer interest in post-war Jeeps resulting in an effort to create "new features" for four wheel drive vehicles. .[6] In the same article, however, the author noted, while addressing the issue of rollover, that a 20% increase in track width would result in a 32% increase in the side force necessary to overturn a vehicle on a 20 degree side slope with a center of gravity at 26". Although a minor point in the article, the comment speaks volumes about the industry's awareness of rollover potential in vehicles that are tall and narrow.

In 1969, General Motors [GM] published two internal reports in response to Consumer Union's revealing that it was considering adoption of task performance-based handling tests. GM reported that it had selected seven [7] test scenarios that it felt represented situations that a consumer might encounter in real life.[7]

GM's study included constant radius cornering, evasive performance, skid recovery, braking in a constant radius turn, air-out recovery, off-road recovery, and steady state lateral acceleration. GM's goal was to create a set of tests to characterize safety-related handling performance in meaningful objective terms.

The Vehicle Dynamics and Road Handling Ability subcommittee of the Industry Standards Organization [ISO] first addressed a need for and interest in a dynamic test maneuver in the early 1970's. The German delegation initially submitted a proposal for the adoption of a double lane change maneuver that measured performance based on time of completion of the test. The U.S. delegation suggested adding throttle lock and modifying geometry of the maneuver so that speed was reduced. Alfa Romeo, Fiat, and Nissan evaluated the proposed maneuver and reported driver variability. GM focused its efforts on "surprise intrusion maneuvers". Toyota studied evasive maneuvers and reported an upper limit of steering capability in typical drivers. Nissan conducted surprise intrusion maneuvers and reported that unskilled drivers used similar steering as expert drivers, but that typical consumers tend to counter-steer more creating larger oscillations in the vehicle. Given that the addition of braking complicated the test procedures, the U.S. delegation proposed making the test pure steering. [8]

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6 See, SAE 660125: "*New Features for Four Wheel Drive Vehicles*", Axelrad, Ford Motor Company [1966].

7 See, GM Internal Report A-2561: "*Development of Task Performance Handling Tests*", Bundorf [3-10-69].

8 See, SAE 760351: "*Test Procedures for Studying Vehicle Dynamics in Lane Change Maneuvers"*, Fancher/Segal/Bernard/Ervin, [1976].

As a result of the foregoing, the ISO adopted a "lane change" maneuver that simulates a double lane change. The maneuver adopted, however, allowed the vehicle to stabilize between the steer events. By allowing the vehicle to stabilize before the reverse steer maneuver, the test moves into the unrealistic zone and removes the emergency nature of the maneuver from the evaluation.

Probably due to the Jeep experience, Ford began to focus time and research on considerations in evaluating handling requirements. Due primarily to its conclusion that inexperienced drivers tend to rely on braking as opposed to steering, Ford focused on subjective evaluation as the chief tool in evaluating vehicle dynamic performance. In the same breath, however, Ford made passing reference to common control problems experienced by consumers – fishtailing, excessive oscillations, insufficient yaw damping – which occur during "rapid lane change maneuvers" or "sharp entry into a turn" type maneuvers. [9]

The need to focus on vehicle design versus driver behavior was further emphasized that same year when Professor McFarland noted that "safety experts believe it is unlikely that significant improvements can be gained from improving or changing the habits of drivers." Instead, improvement in vehicle design offered the "greatest promise." .[10]

In 1973, NHTSA issued a Notice of Proposed Rulemaking [NPRM] to investigate the creation of a test procedure for evaluating rollover resistance. The government's sudden interest in rollover resistance focused the industry on conducting limit maneuvers and resulted in the following interesting results and conclusions:

- Rollover studies using SAE J857a [towing shoe] in combination with a steering actuator to compare rollover properties of various vehicles. [11]

- The ability to define the rollover threshold using a "2 turn" maneuver with outriggers. [12]

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[9] See, SAE 690234: "*Considerations in Determining Vehicle Handling Requirements"*, Bergman, Ford Motor Company [1969].

[10] See, SAE 690795: "*Significant Trends in Human Factors Research on Motor Vehicle Accidents*", McFarland, Harvard [1969].

[11] See, 1-29-71 internal document from Ford Motor Company.

[12] See, 5-10-71 internal Ford report on development of 2 turn maneuver.

- The use of steering actuators, "super human inputs", with and without brakes, in S turn maneuvers to determine whether vehicles are susceptible to rolling. [13]

- The rollover threshold is defined by the rigid body geometry of the vehicle [t/2h] and any unique suspension characteristics associated with the design.[14]

- Ford's represenation that a rollover standard is unnecessary because its passenger carrying vehicles are designed to "slide rather than roll" in extreme, panic oriented maneuvers by consumers. [15]

- After running 7 vehicles through 500 test runs, concluding that "untripped rollover [friction trip] is difficult to predict or accomplish with current vehicles" but "rollover response is dominated by the vehicle's rigid body geometry." [16]

One of the more significant research papers published during the era was a study of vehicle handling by Ford Motor Company's Walter Bergman. Published in May of 1973 [SAE 730492: Measurement and Subjective Evaluation of Vehicle Handling], Mr. Bergman was one of the first industry researchers to place emphasis on the importance of vehicle design in <u>emergency driving situations</u> and the absolute necessity of testing designs at the limit to ensure vehicle response is both predictable and safe. Some of Mr. Bergman's more relevant conclusions are summarized as follows:

- Vehicle properties [design] likewise play a significant role especially in "emergencies."

- Most differences between vehicle designs become noticeable only in "emergencies."

- Subjective evaluations are biased and inadequate for purposes of true evaluation of vehicle performance.

- Rapid steer reversals [double lane change maneuvers] are "key factors" to evaluate.

Mr. Bergman's conclusions can be used as the foundation for the scientific need to test at the limit and can also serve to refute any industry argument that sub-limit or "soft" testing is adequate from a safety standpoint.

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13 See, 9-9-71 internal Ford report on 2 turn testing of a Bronco.

14 SAE 750115: "*The Role of Vehicle Handling in Accident Causation*", I.S. Jones [1975].

15 See, Letter from Ford to NHTSA, 8-15-73 [Ford internal document 20227-52].

16 See, DOT HS-6-01382: Development of Vehicle Rollover Maneuver; I.S. Jones, Rice, Segal [1978].

Following the publication by Bergman, the Highway Safety Research Institute [HSRI] at the University of Michigan published a study presenting what it considered to be a "state of the art" review and analysis of the use of "lane change" maneuvers to evaluate vehicle performance. [See footnote 7]. The researchers at HSRI reached the following important conclusions relevant to the issue of vehicle testing:

- The "lane change" maneuver emphasizes an important facet of vehicle performance, is representative of frequently performed maneuvers, and discriminates between vehicles in terms of performance.

- The "lane change" maneuver is defined as "any vehicle maneuver in which steering is first applied in one direction to displace the vehicle laterally and then the steering is reversed in the other direction while maintaining directional control and recovering the original direction of travel at a lateral displacement of approximately one lane width."

- The lane-change maneuver provides a "critical test of the timing of the yawing and sideslip response of a vehicle", which are influenced by roll response.

- Every driver performs numerous lane changes to resolve conflicts that occur "routinely", and, in extreme conditions, "a very rapid lane change is sometimes required to avoid colliding with a suddenly appearing obstacle."

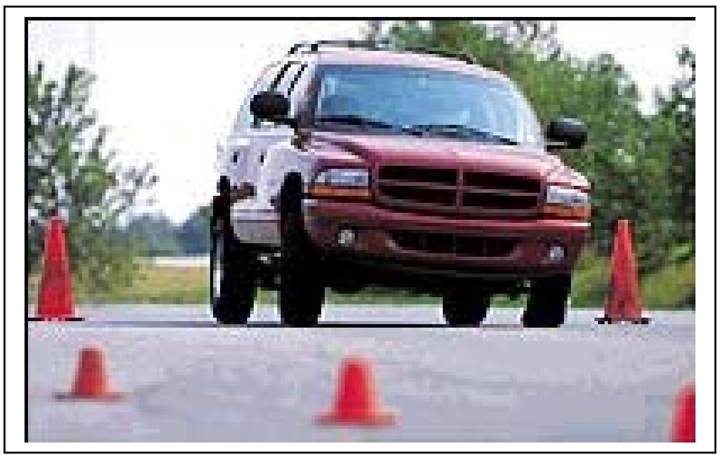
The foregoing study should put to rest any question about the relevance and significance of rapid double lane change maneuvers in every day driving, including the need to assess vehicle performance at the extremes.

Although both tests existed in one form or the other, 60 Minutes expose on the Jeep CJ using J turn and lane change/obstacle avoidance tests reinforced both the need for rollover resistance testing and the fatal consequences associated with vehicle rollover. As a direct result of the images shown on the 60 Minutes program, the industry was forced to again reevaluate vehicle design and begin looking at severe handling maneuvers designed to test the very limits of performance to ensure stability in critical driving situations.

Despite the image of the Jeep CJ flipping in ordinary turning maneuvers, virtually every manufacturer began ushering in the 1980's with its own version of an SUV, all patterned after the Jeep CJ. Instead of sticking to the time-honored standard of designing passenger-carrying vehicles to "slide" rather than roll, the industry turned defensive and began focusing on driver studies with an aim at twisting the results to more narrowly define "human capabilities in emergency situations." In short, the more narrowly they defined human capability, the less severe the requirement for testing.

Although virtually every manufacturer currently uses some form of "limit testing" for evaluation or vehicle development, the industry still maintains that there is no accepted method of evaluating a vehicle's rollover resistance, there is no single available procedure for adequately evaluating rollover, and that rollovers are random, complicated events caused by drivers and environments as opposed to vehicle design, all of which is contrary to their own internal research.

A distinction needs to be made between "vehicle characterization" tests and tests designed to determine the true rollover threshold of a vehicle when subjected to driver steering input.



Although sometimes portrayed as "handling and stability" tests, "vehicle characterization" tests are <u>not</u> designed to test the literal limits of a vehicle's performance. Rather, "vehicle characterization" tests are designed to obtain information about the physical qualities of a vehicle in an objective sense. Examples of such tests include serpentine or slalom maneuvers, steady state turns, circle or radius turns, tangent turns, swept steer procedures, 100′ spiral out tests, and mild or low speed step steer maneuvers. The tests are not designed to exceed .5 g's. The vehicles are typically instrumented with the primary focus being on data reduction and analysis. The tests are <u>not</u> limit maneuvers and do not represent realistic efforts to define the roll threshold or whether the vehicle design has a built in margin of safety for the consumer.

Limit testing, on the other hand, is designed to push the vehicle to the limit in an effort to determine whether the vehicle is subject to rolling given a combination of driver steering and tire friction forces. Although a wide variety of maneuvers exist, the most commonly discussed include the J-turn, Double Lane Change or Obstacle Avoidance maneuvers like the CU maneuver, Fishhook tests, and combination brake and steer maneuvers. Although efforts have been made to reach a common ground on "the" appropriate dynamic test for evaluating rollover resistance, to date all such efforts have been rejected by the industry, which leads to the ultimate issue of what maneuver or combination of maneuvers should be used?

As a general proposition, a vehicle's rollover threshold is maneuver sensitive taking into account speed and the amount and timing of steering input and steering rate. The most demanding maneuver has historically been found to include a combined braking and steering maneuver that could occur in an obstacle-avoidance scenario in which the driver steers, then brakes sufficiently to lock all wheels, and then releases the brake when he feels the vehicle beginning to slide sideways. Experimentation using this sequence in a representative sample of 1970's vintage vehicles showed that a number of the vehicles could <u>not</u> be rolled under any set of circumstances, but some could.[17] Given the addition of Antilock Brake Systems [ABS] on current production vehicles, the combination brake and steer maneuver may no longer be so unrealistic in terms of real-world dynamics.

The following is a brief description of several of the more frequently used/cited limit maneuvers:

A. DRASTIC BRAKE AND TURN:

The maneuver begins in a straightaway and consists of throttling back and applying a ½ sine-wave steering input and then applying the brakes for ½ second sufficiently hard to result in wheel lock-up. The goal is to lock the wheels when the vehicle has reached its maximum yaw rate in response to the steering input. For a given speed, the timing of the brake application and release and the amplitude and period of the sine-wave will dictate the response of the vehicle. In other words, timing and phasing of motions is critical. Typically, finding the appropriate combination takes a large number of test runs.

B. J-TURN MANEUVER:

As the title suggests, a J turn maneuver consists of a turn that forms the shape of a J. The maneuver begins in a straightaway with the vehicle traveling at the desired constant speed. At a designated point, the driver performs a predetermined steering input at a predetermined rate [e.g., 270 degrees @ 500 degrees per second]. The maneuver can be conducted with or without throttle. The steering input is held in place until the vehicle either completes a J, rolls or plows. In comparative testing, typical passenger cars

[17] See, Ervin, R.D., et al, *Vehicle Handling Performance*, Final Report, HSRI, 3 Volumes, UM-HSRI-PF-72, sponsored by NHTSA, Contract No. DOT-HS-031-1-159 [11-72].

remained stable with no suggestion of rollover despite lateral accelerations in the range of .9 g.[18] A wide variety of SUV's have demonstrated a tendency to lift wheels in this maneuver.

C. DOUBLE LANE CHANGE MANEUVERS:

Double lane change maneuvers are designed to simulate accident avoidance maneuvers and address the use of vehicle steering. Rather than truly measuring driver response to an emergency, these maneuvers are designed to measure performance of the vehicle in a wide variety of possible responses to a crisis faced by a driver in the real world. The maneuver is clearly distinguishable from a surprise intrusion test in that the course is predetermined with the use of cones and the driver is fully aware of the necessity for a two turn maneuver.

D. FISHHOOK:

Originally developed by Toyota, this maneuver attempts to induce 2 wheel lift at a lower lateral acceleration than the J Turn by suddenly making a large turn and then turning back even farther in the opposite direction. Following the second turn, the steering wheel is held fixed for the remainder of the test. The maneuver models what might happen when a driver performs a double lane change or 2 wheels off-road recovery maneuver. The maneuver can be conducted using a fixed 270 degree initial steering input as specified in Toyota Engineering Standard TS-A1544. NHTSA recently used a modified version of the test that incorporated an initial steer of 7.5 times the overall steering ratio and modified the timing of the steer reversal.

3. DOES DYNAMIC TESTING DISCRIMINATE BETWEEN GOOD AND BAD DESIGNS?

Whether a given vehicle rolls over in an experiment or test depends on the design of the vehicle. Although this may sound like a simple proposition, the industry repeatedly tries to confuse the issue of dynamic testing by claiming that avoidance-maneuver testing does not "discriminate" between good and bad vehicles: those that lift wheels off the ground versus those that remain stable. The docket is full of industry rhetoric claiming that avoidance tests – like the CU maneuver – do NOT discriminate between those that are good and those that are bad, and that vehicle design is not relevant. The following is an excerpt from the sworn testimony of one of Suzuki and Isuzu's vehicle design "experts" addressing the issue of the role of design in whether a vehicle lifts wheels in the CU maneuver:

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[18] See footnote 4, page 45.

Q: I am talking about in these tests where your folks were deliberately trying to make it [the Wrangler] go up on 2 wheels and you could not. … What I am asking is could you redesign the suspension system so it would go up on 2 wheels?

A: Of the Wrangler?

Q: Yes.

A: Of course.

Q: Could you likewise redesign the Samurai to perform like the Wrangler and <u>not</u> lift wheels?

A: Probably.[19]

As Dr. McCarthy even conceded, the CU test does in fact discriminate between those vehicle designs that will lift wheels versus those that will not, and that he is smart enough to redesign the vehicles to either make them lift wheels or NOT make them lift wheels.

4. DEFINING THE OUTER LIMITS OF PERFORMANCE

A fundamental design goal is to design a vehicle with a margin of safety so that the ultimate user of the product, in this case a vehicle, will not exceed the capacity of the vehicle in a foreseeable turning maneuver. As published internally by Ford Motor Company, a "vehicle should remain stable under all foreseeable operating conditions."

A. DIRECTIONAL STABILITY

A significant number of commenters argue that rollover is always preceded by loss of directional stability and that the focus should be on reducing loss of control as opposed to actual vehicle rollover. As the following testimony from the Engineering Director for Truck Products at Ford Motor Company, Thomas Baughman, demonstrates, the industry is not uniform in this belief. Moreover, as Mr. Baughman points out, the issue of loss of vehicle control is a design issue, not a consumer issue:

Q: Would you agree with the statement that nearly all SUV

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[19] Deposition of Roger McCarthy, <u>Suzuki v. Consumer's Union</u>, April 16, 1999.

rollovers are precipitated by some loss of directional stability?

A: No, I don't think I would. [20]

The following additional excerpt from Mr. Baughman's testimony further defines how a vehicle should be designed from a controllability standpoint and emphasizes that vehicle controllability is an issue of vehicle design:

Q: Understeer and oversteer in common language, you are basically saying you want to maintain directional stability of the vehicle?

A: That's correct.

Q: You don't want the back end sliding around on you?

A: The back end sliding around would be a very simplistic definition of oversteer, yes.

Q: And if the back end slides around, why is that bad?

A: It can result in a loss of control of the vehicle. In actual practice probably what is the worst thing that happens is that a driver who may not be an experienced driver will tend to then take the steering wheel the opposite direction trying to steer into the skid and, depending on the circumstances, particularly at these very high speeds and very high J-turn limit kind of maneuvers, he can actually lose control of the vehicle not in the first maneuver, but in actually his correction to the first maneuver.

Q: And typical reaction would tell somebody when your back end begins to slide around that you probably ought to turn into the –

A: That's what we are all taught in driver's school.

[20] Deposition testimony of Thomas Baughman, August 2, 2001, at page 434.

Q: And from a vehicle design standpoint, what you would like to have is a vehicle that plows out or continues to understeer as opposed to spins out?

A: All Ford Motor Company products are designed with inherent understeer into them, as I believe probably every vehicle designed by any manufacturer on the road today is. Understeer is an inherent capability of the vehicle that helps ensure that the vehicle always stays under control. [21]

As stated by Mr. Baughman and Ford, the vehicle should be designed to be forgiving in emergency situations. If the vehicle is designed so that it avoids placing the consumer in a marginal situation, the consumer will not be required to mentally respond to a vehicle that is behaving contrary to what is anticipated. As best put by Mitsubishi in a recent scientific paper:

> Once a vehicle enters a marginal condition, a driver has hardly enough time to control a vehicle. It is the most effective that a vehicle never approaches a marginal condition and a driver never has an excessive mental tension. [22]

The foregoing is included to emphasize that the focus on directional stability is inherently a vehicle systems issue as opposed to a "consumer information" issue thus further supporting the proposition that we must have a dynamic test procedure that exercises the design at the very thresholds to ensure that the vehicle is controllable under all foreseeable operating conditions.

B. WHAT ARE "FORESEEABLE OPERATING CONDITIONS"?

Some industry supporters wish to split hairs over what is a "foreseeable operating condition." Instead of arguing over what could or might be a foreseeable operating condition, reference to industry literature is the easiest method of defining what is "foreseeable" from a consumer standpoint.

Any analysis of consumer operation of motor vehicles begins with the fundamental proposition that no two drivers will likely operate their vehicle the same in an emergency

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[21] Deposition testimony of Thomas Baughman, Bailey v. Ford, December 21, 2000, at pages 29-30.

[22] Yoshida, et al, "*Traction Control Technology for Improved Driving Safety*", Paper S7-0-03 [2000].

situation. Stated slightly differently, BMW noted in a recent scientific publication that:

> Depending on their driving experience, the safety margin of car drivers in different driving situations can differ significantly. … In situations, when no special reactions are required, average drivers as well as professional drivers control their car within the stable range with sufficient safety reserve. [23]

A variety of driver response studies have been carried out over the years aimed at determining where the outer limit of consumer performance is in terms of steering wheel inputs and rates. The aim is to determine the envelope of foreseeable use of the vehicle during an emergency. Once the threshold of likely consumer performance is determined, the focus should be on exceeding that threshold by design so that a margin of safety exists for the consumer. This concept was best stated by Ford Motor Company in the mid-1970's when it told NHTSA that a rollover standard was unnecessary because Ford passenger carrying vehicles are designed to be "forgiving" and to "slide rather than roll" in extreme, panic oriented maneuvers by consumers. [see footnote 15]

The following is an overview of some of the more important driver response studies:

MAN OFF THE STREET STUDY:
R.S. Rice and F. Dell'Amico
Calspan Report No. Z5-5208-K-1
March, 1974
Final Report – Prepared for GM

"GM has had a long-term interest in driver characteristics and capabilities and how these are affected by driver training. The Corporation has performed numerous in-house projects and experiments in these areas."

- "One set of findings … suggested that ordinary drivers seldom utilize the maneuvering capability of automobiles even in emergency situations. Additionally, in these experiments drivers did not always react in the most appropriate manner."

- "A basic objective of the present program was to acquire additional information on driver behavior in maneuvers at acclerations higher than those normally used in vehicle operation on the highway."

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[23] Leffler, "*Improvements in Active Safety by Innovation for Active Stability Control*", SAE 900209.

- "The driver sample was chosen to cover a substantial range of probable driver behavior and all of the subjects involved were volunteers. The instructions given to the drivers were intended to induce rapid maneuvers by providing an incentive and a competitive environment, to drive the course as fast as they were willing. Additionally, some subjects were exposed to a definite emergency situation."

- "It was intended that these tasks have some relationship to those encountered in actual highway operation but, of course, the experiment was set up to safeguard the participants and all of the subjects were aware of the fact that they were not being exposed to the risks attendant to actual highway conditions."

J

- The objective was to obtain a variety of observations and measurements from a large group of drivers when motivated to drive aggressively over a closed course

- 100 test subjects and group of three expert drivers.
- Geometry of the incidents designed to simulate situations encountered on the road.
- Average peak rates of 850 degree per second of steer input.
- 11 drivers used rates in excess of 1000 degrees per second.
- Expert drivers used rates up to 800 degrees per second.

NISSAN STUDY:

1977

SAE 770130

"Performance Driver-Vehicle System in Emergency Avoidance"

Maeda, et al of Nissan

- "The reaction of a driver to an emergency includes [a] application of the brakes; [b] turning of the steering wheel to avoid an accident; and [c] utilization of both brakes and steering wheel."

- " ... some automoble accidents are caused when the driver, surprised at the sudden appearance of an obstacle in his view, turns the steering wheel so abruptly that the vehicle goes out of control. Often such emergencies are experienced on expressways, the result of which is often a serious accident."

- "The purpose of our study was to analyze the characteristics of driver-vehicle systems when the steering wheel is turned to avoid an emergency, and this paper describes how we simulated on the test track a condition where the driver had to avoid a collision with an obstacle suddenly jumping into his path."

- Used drivers of differing abilities.
- Simulated emergencies that might be encountered.
- Used 60 kph on dry asphalt.
- Drivers were told not to use braking.
- Also included a "surprise" intrusion test.
- More than 1 second of reaction to emergency was required.
- Found the same steering pattern regardless of whether the driver was informed of the intrusion or obstacle in advance.
- Used steer angle as input and yaw velocity as output.

- > 20 drivers.

- "The maximum steering wheel angles in the first steer input for emergency avoidance are concentrated in the range of ... 200-230 degrees ... This generally corresponds with the maximum steering wheel angle to which the steering wheel can be turned with the hands kept on the same parts on it. The maximum steering angular velocities in the first steer input are concentrated in the range of ... 700-900 degrees per second ... and thus indicated that driver's steering operations are extremely quick. In both, there is <u>no</u> difference between experienced and inexperienced drivers."

- "In control steer [the last attempt at correction], however, an appreciable difference is seen between experienced and inexperienced drivers."

- They modeled the system and did simulations with a computer

- "When the yaw response lag time is too great to compensate for, the driver feels uneasy about the condition and thus turns the steering wheel excessively. Therefore, when the yaw reaches the rate desired by the driver, even though he carries out the steering turning back, an unexpected yaw rate is caused by the preceding steering operation. The corrective steer, therefore, causes a still greater steering angle. The subsequent corrective steer also causes a greater steering angle so that the vehicle zigzags out of control. As a result, the vehicle runs off onto the shoulder of the road or over a median strip ... and ... out of control..."

TOYOTA:
1996
"Influence of ABS on Rollover Accidents"
96-S5-0-04

- Yamamoto and Kimura
- Analyzed human behavior in driving to identify increase in rollover crashes

- IIHS and NHTSA say ABS has caused more rollover crashes
- When avoiding objects, driver's concentrate on steering, not brakes
- Sudden, unexpected intrusion at 80 kph
- Used 38 drivers aged 22-56
- 91% failed to avoid the obstacle when given 1 to 1.5 seconds to avoid
- 48% failed to avoid the obstacle when given 1.8 to 2 seconds to avoid
- 50% did not activate the ABS, which means driver's tend to steer
- Then used experts with initial steer input of 90-160 degrees
- Concludes that ABS helps because they run off the road v. spin the vehicle

NHTSA STUDY
1999
"Driver Crash Avoidance Behavior with ABS in an Intersection Incursion Scenario on Dry Versus Wet Pavement"
1999-01-1288 [reprinted from SP-1413]
Mazzae/Barickman/Baldwin/Forkenbrock

- Examined driver crash avoidance behavior and effect of ABS on ability to avoid collision.
- Drivers tend to brake and steer
- Excessive steering can occur
- Kahane concluded that ABS results in more run off the road crashes
- ABS prevents wheel-lock-up, but allows drivers to continue to steer
- Allowed examination of drivers in realistic environment with repeatable test method
- 192 people for dry pavement study
- All 25-55 years of age
- None had ABS
- 7% were professional truck drivers and 4% drove as occupation
- Used 95 Lumina and 96 Taurus
- 45 mph on drive pavement with friction coefficient of .9
- Instrumented vehicles with video
- Surprise intrusion test used with 2.5 second interval for reaction
- 94% both steered and braked
- 46% of the 98% steered first
- 63% steered left first
- Average steer input was 53 degrees
- Highest steer input was 271 degrees
- Average max steer rate was 262 degrees per second
- Highest max steer rate was 1159 degrees per second
- 5% of steer rates were greater than 600 degrees per second

UNIVERSITY OF IOWA

1999

"Driver Crash Avoidance Behavior with ABS in an Intersection Incursion Scenario on the Iowa Driving Simulator"

1999-01-1290

Mazzae/Baldwin/McGhee

- 120 people ages 25-55
- ½ got ABS instruction and ½ did not
- 45-55 mph used
- Used both wet and dry surfaces
- Used surprise intrusion test
- All 120 attempted both steering and braking
- 79% braked first
- 4% braked and steered simultaneously
- 17% steered first
- 86% steered left first
- Average steer input was 148 degrees
- Average steer input was 192 degrees for conventional [non-ABS] vehicles
- Highest steer input was 540 degrees
- Average steer rate was 514 deg/second
- Highest observed steer rate was 1416 deg/second
- 5% of all steer rates were greater than 981 deg/second
- 35% hit the object

BARTLETT STUDY:

2000

"Driver Abilities in Closed Course Testing"

2000-01-0179

- Reports on ability of large sample of drivers as they negotiated closed cone-marked course using 2 modern vehicles.
- Typical steer rates are higher than earlier reported values
- The willingness limits were identical regardless of the vehicle
- Used 2 police package vehicles [Lumina and Caprice]
- 467 drivers used [418 males]
- Max steer rate over 100 ms was 1199 for males and 959 for females
- Max steer rate over 200 ms was 1149 for males and 919 for females

The foregoing studies clearly demonstrate that driver's do steer quite aggressively when faced with emergency situations and that the amount and rate of steering far exceeds the industry's current design capacity for vehicles, including SUV's.

The following are answers to specific questions posed:

1. IS A DYNAMIC TEST THE BEST APPROACH?

For the reasons set forth above, yes. A dynamic test or combination of tests should be mandated. Although some argue that the type of maneuvers under consideration – lane change-type maneuvers – are not "realistic" in the real world, the following excerpt from a Ford Motor Company internal document show that these arguments are simply false:

> A lane change test represents a real world maneuver. It is very common for an obstacle to appear in the path of a vehicle in which case the driver will have to steer the vehicle to move it into the adjacent lane to avoid hitting this object.[24]

Lane change-type maneuvers are foreseeable events that consumers perform on a daily basis. A vehicle should be designed to handle this type maneuver with a significant margin of safety.

2. ARE THERE ADDITIONAL MANEUVERS NHTSA SHOULD EVALUATE?

The ones currently under evaluation, including variations of those maneuvers, are adequate.

3. WHICH MANEUVER OR COMBINATION OF MANEUVERS IS BEST?

NHTSA's test protocal should include a multi-steer event, preferably 2-3 steers, as well as a step steer as in the J-Turn maneuver. Analysis of the roll angles, maximum lateral acceleration, lateral load transfer characteristics, and yaw rate tendencies of the vehicle should be evaluated in each of the maneuvers. The protocal should also assess the effect of roll momentum of the vehicle with an effort aimed at determining the natural resonance/frequency of the roll response in multiple steer events. These goals can be accomplished through the use of the CU maneuver, the Fishhook maneuver, and the J-Turn maneuver.

4. WHAT INDICATORS OF HANDLING WOULD BE APPROPRIATE TO

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[24] Boyd, *Objective Evaluation of Lane Change Performance Using Path Correction*, June 22, 1992.

MEASURE?

The most important criteria should be whether the vehicle remains controllable at foreseeable speeds, steering inputs and rates, and on courses that are representative of real world requirements, and the wheels should remain on the pavement in the emergency turning maneuver. Whether the vehicle plows out or spins out is likewise important from a consumer rating standpoint. In addition to maximum lateral accelerations, lateral load transfer functions, and roll angle data, I would urge that tire debeading in hard cornering be considered as well.

5. HOW IMPORTANT IS OBJECTIVITY AND REPEATABILITY?

Although objectivity and repeatability are clearly important characteristics of any test, the more significant issue is whether the demands of the test are rigorous enough to simulate driver behavior in the real world. For instance, driver variability is always an issue in the real world because every driver will respond or react differently in a given situation. The issue is not whether each driver will drive differently, but whether the vehicle is capable of performing safely at the upper limits of human steering capability so that a margin of safety is present in the design.

6. WHAT CRITERIA SHOULD NHTSA USE TO SELECT THE BEST VEHICLE MANEUVER TEST FOR ROLLOVER RESISTANCE?

Criteria could include a comparison of SSF [t/2h], wheel lift characteristics in the dynamic maneuvers with steering wheel inputs and rates provided, lateral acceleration levels, roll angles, lateral load transfer quantification, yaw rate information, spin out/plow out, and a total rating scale in terms of risk of poor performance [wheel lift or spin out] in a dynamic maneuver.

CONCLUSION

Dynamic rollover testing is necessary. A test or combination of tests are needed to ensure that the vehicle capacity is well-defined and that a safety margin is built into the design to ensure that the vehicle performs safely within the envelope of likely consumer behavior as defined by the driver studies performed in and out of the industry. So long as the industry continues to make huge profits marketing SUV's for consumer use as "station wagon replacements", the consumer is at risk. Dynamic testing to ensure stability should be mandatory.

Cordially yours,

Tab Turner

CTT/bg